Multivariate Analysis of Trip Chaining Behaviour

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Abstract

This paper examines the relationship between patterns of trip chaining and urban form. The goal is to examine whether lower density environments are related to more frequent reliance upon trip chaining and more complex tours. The analysis uses the 2001 National Household Travel Survey to evaluate household, individual travel and trip characteristics alongside a basic measure of residential density. Two estimation techniques, the Ordered Probit and the Negative Binomial model are used to evaluate the factors associated with the tendency to combine trips into more complex tours, measured as number of stops. The results indicate that, controlling for key household and traveler characteristics, lower density environments lead to both a greater reliance upon trip chaining and tours that involve more stops along the way. This is followed by a household level analysis of tour generation. Crane (1996) and Krizek (2003) suggested that more accessible areas will tend to generate more tours. However, we found no evidence for this in our analysis.

Introduction

The study of trip chaining has a long history in the transportation literature. Early studies tested theories explaining why individual trips would be combined into larger tours. Further research quantified variables that predicted such patterns of travel. The continued development of trip chaining research has even led some regions, to formally incorporate the idea of forecasting tours into their travel demand models. A wide range of studies on land use and travel behavior has also clarified our understanding of how urban form shapes trip generation, total miles traveled and the mode of travel by households (Ewing and Cervero 2001, Boarnet and Crane 2001, Kuzmyak et al 2003).

Most trip chaining research has examined the demographic factors associated with the need to chain trips. The classic example is the school or daycare trip – dropping children off on the way to work. Other trips, however, may have much more complexity, such as shopping trips that involve multiple destinations, all of which require a car. These may be less dependent on demographic factors, such as the number of children in a household or the age of individuals in the household and more dependent upon land use relationships.

Much less is known about the specific relationships between land use patterns and trip chaining as a travel choice. Specifically, to what extent is urban form related to a tendency to combine trips or to make more complex tours? Trip chaining may be an adaptation to the low levels of accessibility found in many suburban environments or, conversely, to the difficulty of automobile travel in higher density neighborhoods. It is generally believed that trip chaining can be a relatively efficient means of accessing multiple destinations, resulting in less travel. Most research in this area has considered this to be beneficial, without considering the potential planning costs associated with complex trips. In other words, all else equal, most households would achieve greater utility from simpler trips and only plan and then chain trips to avoid other more costly alternatives.

These issues could have interesting policy implications. If more complex trips and their associated planning costs are associated with dispersed land use patterns then it provides a further rationale for emphasizing more accessible land use. If higher density leads to more complex trips then more work is needed to determine if trip chaining in more dense urban environments increases the number of trips or overall miles of vehicle travel. For example, if higher density is related to making more linked trips and tours with multiple stops, it could be the result of tours that combine car travel with walking or transit. A relationship between greater density and more complex trips could also be the product of tours with more stops, but much shorter trips.

The primary focus of this study is the effect of residential density on 1) the probability of a household making complex tours, and 2) how this interacts with household tour generation. As with many other studies we explicitly include variables that account for household structure and individual traveler characteristics. The availability of a tour-based dataset from the 2001 National Household Travel Survey and its inclusion of land use variables create new opportunities for analysis. Unlike previous studies, which mostly focus on single regions, this dataset enables consideration of trip chaining across a wide range of urban contexts with a large number of observations.

Previous Studies

Beginning in the late 1970's studies began to examine trip chaining as a specific form of travel behavior, with the objective of improving travel demand modeling procedures. In their seminal work on the subject, Adler and Ben-Akiva (1979) argued that existing transportation forecasting models neglected the fact that many trips were not independent, but a related set of decisions by households. To validate this idea, they defined a behavioral model to estimate optimal travel patterns, and an empirical model based on actual household travel survey data. They used these models to examine how people adapt to various constraints.

Subsequent research more formally connected trip chaining to the four-step travel demand forecasting process. Kitamura (1984) tested the presumption that destination choice could be better explained when trip destination and trip chaining were considered as interrelated travel choices. Goulias et al. (1988) further examined the set of choices related to trip chaining by estimating a set of trip generation models –work, school, shopping, social, personal business and passenger serving- then using instrumental variables to test their relationship to predicting trip chaining. Their results indicated that work, shopping, and personal business trips were the most likely to be combined into tours. Additionally, they estimated models based on data from Detroit and The Netherlands and found slightly different relationships. They attributed these findings to the differences in land use patterns, cultural and institutional factors, but lacked the data to consider the issue empirically.

Other studies have focused on household structure as a key factor behind trip chaining as a travel behavior. In particular, income levels and number of children in the household, along with the age and gender of the traveler influence the tendency to combine trips. Using data from the 1995 Nationwide Personal Transportation Survey, McGuckin and Murakami (1999) compared how women's travel patterns differed from men. Overall women were more likely than men to make multi-stop trips, particularly to and from work. The differences were even more substantial for women with children and single mothers in particular.

Most research in this area seems to accept that trip chaining is the product of five basic types of characteristics 1) the household, 2) the primary traveler, 3) the trips being made, 4) the transportation system and 5) land use patterns. However, differences in the analytical approach (behavioral, or cross sectional studies estimated from travel surveys) and the primary dependent variable examined (number of tours, number of trips within a tour, total miles in a tour, etc) leave important gaps in our understanding.

For example, two studies from the urbanized area of Seattle in the State of Washington, examined the relationship between land use patterns and trip chaining, but came to slightly different conclusions. A study by Wallace et al (2000) evaluated forces shaping the complexity of travel tours and specifically considered whether a journey originated in an urban center. They found that, controlling for household characteristics, tours based in urban centers included fewer trip links. According to the authors, it implied that those living outside urban centers were more likely to plan complex tours to accomplish their travel goals. Krizek (2000) looked at the travel patterns of households that moved between Seattle area neighborhoods with differing levels of accessibility. He found that households moving from low to medium density neighborhoods made shorter tours following their relocation, but showed no difference in the complexity of their tours. Both studies tend to support the idea that trip chaining is a response to less accessible urban environments, but differ on whether it leads to more complex tours or tours of greater overall length.

Crane (1996) developed a conceptual model to try to explain the impact of greater accessibility on total travel. This leads to a trade-off. Those living in more accessible areas make more trips than those living in less accessible areas. However, the trip lengths in more accessible areas are shorter compared to those who are living in less accessible areas. Crane concluded that more accessible areas may lead to more total travel. Krizek (2003) could not refute this hypothesis in his analysis of Seattle data; our analysis examines this trade-off using national data.

The extensive body of research more broadly examining the relationship between land use and travel behavior has also generated findings relevant to this study. Although some disagreement still exists around the overall importance of urban form on travel patterns, a general consensus seems to have emerged that regional accessibility (transit focused around mixed-use urban sub-centers) is the most significant factor explaining lower levels of work-related vehicle travel and local accessibility (diverse land use mix at the neighborhood level) is the most significant factor in explaining less non-work vehicle travel (Ewing and Cervero 2001). However, most of this literature examines the combined effect of shorter vehicle trips or shifting to alternative travel modes without explicitly considering trip chaining as an adaptation to more accessible urban forms.

Data and Methodology

The data for this study comes from the 2001 National Household Travel Survey. This nationwide survey was conducted in 2001 and contains data on roughly 642,000 trips made by over 65,000 households. Detailed trip information was collected for individuals and complete households. Demographic information on each household was also collected providing a rich data set for travel analysis. Urban density variables are also included and linked to each household, providing a good measure typically used for evaluating land use effects. The data is statistically representative of the U.S. population.

A separate trip-chaining data set was derived and made available in 2005. This data set contains a variable that indicates whether each record is a single trip or part of a larger tour. The tours were aggregated from trips made by individuals and each tour record provides the number of stops made. Since a stop is defined by a reported dwell time of 30 minutes or less, the trip chains represented by this variable are separated by relatively short periods of time spent at any single destination. This provides a more narrow set of tours that would exclude, for example, a trip to a mall that goes on for an hour, followed by a long lunch and a trip to the grocery store on the way home. Rather, the records defined as tours in the dataset are made up of stops more likely to be for a specific objective and therefore brief.

Our basic methodological approach is to develop multivariate models that examine the impact of residential density, controlling for demographic and other factors commonly associated with travel behavior. The dependent variable is each model is the number of stops in a tour. Both are count variables, which are non-zero and in many instances contain a large number of zero values (some 72.5% of the records are tours with no stops, see Table 1).

Two modeling approaches are commonly used with this type of data. One is a count model such as a Poisson regression or a Negative Binomial regression. The latter is often preferable since it avoids the requirement of Poisson distributions for equivalency of the mean with the variance. An alternative approach, such as an Ordered Probit model, allows for ordinal differences in the dependent variable but does not assume cardinality between preferences (i.e., that the difference between 1 stop and 2 stops is equivalent to that between 3 and 4 stops). The advantage of this technique over the Negative Binomial model is that we can set the "cut points" or the levels that define the dependent variable, thereby eliminating the impact of outliers (e.g., one tour in the data had 23 stops recorded). It may also more appropriately account for the actual behavior, in that the key decision is really the choice to chain trips or not to. Below, we present results from both models and discuss the potential implications of the slight statistical differences found in the results.

The Ordered Probit model has the following general structure:

$$y_n^* = \mathbf{X}_{in}\boldsymbol{\beta}_{in} + \varepsilon_n \tag{1}$$

where y_n* is a latent variable measuring the number of stops or tours in our models. As an example, cut points can be defined as follows:

$$y_i = \begin{cases} 1 \quad \mathit{if} \quad -\infty \le y_i^* \le \mu_1 \\ 2 \quad \mathit{if} \quad \mu_1 \le y_i^* \le \mu_2 \\ \qquad\qquad \vdots \\ \qquad\qquad \vdots \\ n \quad \mathit{if} \quad \mu_n \le y_i^* \le \infty \end{cases} \tag{2}$$

The cut points (i.e., threshold values) μ_m are unknown parameters to be estimated. The partial change in y^* with respect to $\boldsymbol{X}_n$ is $\boldsymbol{\beta}_n$. This implies that for a unit change in $\boldsymbol{X}_n$, y^* is expected to change by $\boldsymbol{\beta}_n$ units, holding all other variables constant. The predicted probability of the decrease, m, for given $\boldsymbol{X}_i$ is

$$\Pr(\mathrm{y} = \mathrm{m} \mid \mathbf{X}_i) = \mathrm{F}(\hat{\mu}_{\mathrm{m}} - \mathbf{X}_i\hat{\boldsymbol{\beta}}) - \mathrm{F}(\hat{\mu}_{\mathrm{m}-1} - \mathbf{X}_i\hat{\boldsymbol{\beta}}) \tag{3}$$

The coefficients ($\hat{\boldsymbol{\beta}}$) and the cut points (μ_m) are estimated using maximum-likelihood estimation. No constant appears in equation (3) as the effect is absorbed into the cut points.

A Negative Binomial model also has the correct distributional properties for model estimation. Negative binomial models are a generalization of the Poission model that can account for overdispersion in the data, or a variance unequal to the mean (Miaou, 1994; Shankar et al., 1995; Vogt and Bared, 1998). Although the source of overdispersion in count data cannot be distinguished, its presence can be adjusted by introducing a stochastic component in the log-linear relationship between the expected numbers of accident in an observation unit i, μ_i and the covariates $\boldsymbol{X}$

$$\ln \tilde{\mu}_i = \boldsymbol{X}_i \boldsymbol{\beta} + \varepsilon_i \tag{2}$$

where $\boldsymbol{\beta}$ is an estimated vector of coefficients representing the effects of the covariates. The term ε is a random error that is assumed to be uncorrelated with $\boldsymbol{X}$. The probability density function for the Negative Binomial distribution can be expressed as

$$\Pr(n_i \mid \mu_i, k) = \frac{\Gamma(n_i + 1/k)}{\Gamma(1/k)\Gamma(n_i + 1)} \left(\frac{k\mu_i}{1 + k\mu_i} \right)^{n_i} \left(\frac{1}{1 + k\mu_i} \right)^{1/k} \tag{3}$$

in which $k(\geq 0)$ is the overdispersion parameter.

Analysis and Results

The NHTS dataset includes more than 620,000 trips reported by households across the country. These trips include a large number of tours, where a household connected several trips, but spent less than 30 minutes at any single stop. As a result the tour dataset includes just over 430,000 cases. 72% included no stops. In other words, they were not considered tours. About 20% had one stop, implying that they were very simple tours that combined just two trips. However, nearly 30,000 tours were more complex in nature, encompassing two or more stops in the journey (Table 1). Several extreme cases can also be found in the data, in one case a reported tour included 23 stops. The dependent variable used in the ordered probit model groups these more extreme cases into a *five or more stops* category to minimize possible outlier effects from the handful of extreme cases in the sample.

A brief examination of the basic patterns in the dataset provides a starting point to examine the impact of the traveler's neighborhood characteristics. As population density increases, households' tours tend to be: shorter in overall length, consist of fewer links of shorter length, and rely less heavily upon personal vehicles (see Table 2). However, as noted in previous studies of trip chaining, it is important to account for differences in the nature of the trips themselves, household structure and traveler characteristics.

Table 3 disaggregates the number of stops by the type of tour identified in the data. Tour types consist of those trips starting or ending at Home, Work or Other, where other is defined as other locations, such as shopping or recreational locations, or any non-home or non-work location. By definition, we would expect Home-Home and Work-Work tours to have at least one stop. However, a small percent of each is reported as having no stop. These could simply be tours that represent travel for the sake of travel[1] or possibly represent data that is incorrectly coded. These records are kept in the subsequent analysis. The vast majority of all tours have no stops. Home-Home and Work-Work tours tend to have more multiple stop tours compared to those with other origins and destinations.

Table 4 provides a simple examination of trip complexity related to household structure. Specifically, the average number of stops in tours is compared across different configurations of adults and children in households. We would expect households with children to make more complex trips. Surprisingly, this cross-tabulation does not show such a pattern. In fact, households with working adults and no children had more tours as a share of their overall trips. However, this pattern does not hold up once other factors are considered through the multivariate analysis discussed below. This difference between the simple cross tabulations and the multivariate results illustrates the problematic nature of studies that rely solely upon such summary statistics and do not control for other household, trip, and land use factors.

The multivariate results are shown in Table 5 for both an Ordered Probit and a Negative Binomial model. The dependent variable in each case is the total number of stops, ranging from

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[1] As Mokhtarian and Salomon (2001) have noted, some trips may be made for the positive utility associated with travel for its own sake, so these reported tours are certainly feasible.

0 to 5 or more in the Ordered Probit model and up to 23 stops in the Negative Binomial model (see Table 1).

For the most part, the models produce similar results, but a few exceptions are notable. Across the household structure variables, the Ordered Probit model has a positive and clearly significant coefficient for *one adult with a child aged at least 6-15*, implying that single parents are more likely to link trips and make more complex tours. In the Negative Binomial model, the coefficient for this variable is a bit more questionable - significant only at a 90% level of confidence. The estimate for a more traditional family structure - *two or more adults with a child aged at least 6-15* is not significant in the Ordered Probit model, but negative and significant in the Negative Binomial model, implying that such households make less complex tours. A similar effect is found for those travelers who combine the use of a car with walking on a tour. The Negative Binomial model indicates a significant negative coefficient (relative to car-only tours), but this relationship is not significant in the Ordered Probit model.

The differences between the models were further investigated with two modifications. First, outlier cases (i.e., the handful of observations with a large numbers of stops) were deleted from the Negative Binomial model. This did not substantively change the results. Next, the Ordered Probit model was also estimated without restricting the cut point levels. Again, no substantive changes occurred in the parameter estimates. Therefore, there seems to be no simple explanation for the modest differences between the two models. One possible explanation is that the Ordered Probit model, which does not account for cardinality between choices, is capturing the effect of whether or not a choice is made to link trips, as it is an ordinal measure. This might be a possible interpretation as the Ordered Probit results are more consistent with behavioral expectations. Since, the Ordered Probit model has a slightly higher pseudo-R^2 value it also suggests more confidence in its results. With this in mind, the remaining discussion focuses primarily on the results of this model.

The key factor of interest for this study is the level of accessibility measured in terms of residiential population density. Although many studies have clarified the important impact of a diverse land use mix and good urban design on travel patterns, density is often used as an imperfect proxy for a number of reasons. First, it tends to be related to these two important urban form characteristics and second, it tends to be related to greater regional accessibility (Cervero and Kockleman 1997, Kuzmyak 2003). The density variable is based upon census tract data as the spatial unit of measurement. Dummy variables are included in the model to reflect the range of residential density in the area around the traveler's home. These were originally included in the model as a continuous variable, based on the mean value of the categories, and showed a significant and negative effect. However, it was unclear whether a linear structure made sense, since there may be critical thresholds, beyond which travel behavior changes dramatically.

The coefficients for the density dummy variables seem to confirm this hypothesis. All are negative and statistically significant relative to the reference case- 50 people per square mile. The magnitude increases with each category of greater density, suggesting that trip complexity decreases more dramatically at higher densities. This seems particularly the case for travelers living in neighborhoods above 10,000 persons per square mile. Therefore, the results do support a relationship between higher population density and less trip chaining. This is consistent with studies such as Krizek (2003) that found less trip chaining when residents moved to more accessible neighborhoods.

Examining demographic variables alongside density also suggest interesting findings relative to previous research that often ignored the impact of urban form. First, age of trip-maker shows a consistent pattern. Travelers over age 25 make more complex trips. This is not surprising and would clearly be consistent with the reality of accumulating more household responsibilities with age. Interestingly, even the oldest age categories show a significant relationship to more complex trip chaining, although the effect is slightly less for those over the age of 76.

Key socioeconomic variables also help explain the relative complexity of trip making. In particular, travelers in households with more adults than cars make more complex tours. All else being equal, more wealthy households also make tours with more stops. As with many of the socioeconomic variables included in the model, the coefficient indicating women make more complex trips than men is consistent with the findings of previous studies (McGuckin and Murakami, 1999; Rosenbloom and Burns, 1993). Ethnicity, on the other and, has a less clear effect. The only indication of an impact is the small negative coefficient indicating Hispanics may have less of a tendency to make complex tours. Differences among occupational categories also show minor differences, with a negative coefficient for workers in the manufacturing sector relative to those with no jobs. Travelers with other occupations had patterns indistinguishable from the reference variable.

Household structure has a strong association with trip complexity that is generally consistent with the conventional wisdom. In particular, adults with a young child aged 0 to 5 have the strongest tendency to link together more trips into a single tour. Relative to one adult with no children, they have a much greater propensity to trip chain. This relationship also holds for households with two adults and a child aged 0 to 5, though the coefficient size is smaller. The effect for one adult with a child aged 6-15 is also positive (though as noted previously, not as highly significant in the Negative Binomial model). In general, other parameters are negative and many are statistically significant. The pattern across the household structure variables seems to indicate that households with a single adult, regardless of the number of children, make more complex trips than those with two adults. As previously noted, this detail was not apparent in the simple cross-tabulation shown in Table 4, revealing the need to control for other factors when analyzing trip chaining.

Finally, tour specific variables were also included in the model. The mix of modes used in the tour was included as a dummy variable, relative to those tours made only by car. As can be seen, journeys where the traveler is not a driver tend to be more complex. The origin and destination points of a tour are also an important control variable. In particular, tours that start and end at home tend to involve more linked trips. This is consistent with an expectation that *errand-running* journeys to accomplish multiple shopping and personal business tasks would tend to be home based. Other types of tours are generally simpler. The cross-tabulations in Table 3 generally confirm this result, with some 14.58% of Home-Home tours having at least 2 stops and 11.63% of Work-Work tours having at least 2 stops, both being a larger fraction compared to other tour types.

Control variables for day of the week and timing of the survey also had an impact. Saturdays generally have the most complex tours, while Sundays have the least. An additional control variable is included to indicate whether data was collected before or after Sept. 11, 2001. This variable is positive indicating a reduction in trip chaining after Sept. 11, 2001. This is probably consistent with reduced economic activity that immediately followed the incidents of Sept. 11, 2001.

More information on substantive relationships can be obtained by examining the percent change in number of stops indicated by the coefficients of each independent variable. In Ordered Probit models, this is done by comparing probability changes against a defined *reference individual*. In this case we define the reference individual with all the dummy variables set equal to 0 and that other variables are set at the sample mean (HH income = $58,898; Ratio of HH members over 16 to vehicles= 1.040; and, Average link speed = 25). The comparison cases for each dummy variable are shown in Table 6. Changes for the continuous variables are based upon a 10% increase in the value of the variable. The first line of the table shows the probabilities associated with the reference case for which each percent change compared to.

The type of tour also shows large percent differences compared to the work based tour (the reference case). With the exception of tours beginning and ending at home, which are more complex, other types of tours tend overwhelmingly to be zero-stop tours (consistent with the cross-tabulation result in Table 3).

The most substantive changes are associated with age relative to those under 16. Gender shows a large difference with men making nearly 10% more zero-stop tours. Amongst the household structure variables, those with one adult and a young child clearly have longer trip chains than others. In comparison, the population density effects are as expected, with more zero-stop tours as density increases and a large increase in simpler trips above a density of 10,000 people per square mile. Additionally, the pattern of reduced trip chaining links is consistent in all cases relative to the low density reference point, suggesting a clear association between less accessible land uses and increases in trip complexity.

A related question is whether total trip making is less in these areas. If less accessibility leads to more complex trip making, is there a trade-off reflected in fewer trips? This was originally proposed by Crane (1996) and was confirmed by the results of Krizek's (2003) study. It is examined in this analysis by aggregating total tours made by each household and estimating both an Ordered Probit and a Negative Binomial model based upon household-specific variables. These are shown in Table 7. No major inconsistencies are found in the relative statistical significance of variables in the two models.

The key variable of interest, population density, is significant but complex in what it reveals. Interestingly, the most complex tours are made in medium density urban areas –

coefficient values are largest for 1000 – 4000 people per square mile. When density exceeds 10,000 people per square mile, the number of tours made drops off, especially for the highest d ensity category, above 25,000 people per square mile. This would tend to refute the hypothesis proposed by Crane (1996); in particular the range of densities that have more tours would fall within suburban areas, while those with the fewest are either very low density rural areas or ultra-high density urban areas. The average tour lengths in higher density areas are also lower than in lower density areas, suggesting that total vehicle mileage is also lower.

The household variables also show an interesting pattern. In general, households with more adults make more tours. These same households tended to have fewer chains within these tours. In addition, retired people are associated with fewer tours, although they did have relatively complex trip chains. Household income is associated, not surprisingly, with more tours. The ratio of household members over 16 to vehicles is also associated with more tours.

Conclusions

The key contribution of this research is to examine the impact residential density has on the complexity of travel tours. By controlling for various household, traveler and trip characteristics, the impact of density can be better understood within the full context of trip chaining. The results indicate increased trip chaining in lower density areas, and that more tours are made in areas with densities typical of suburban areas. Given that this analysis controls for the demographic factors normally associated with complex trip chains and tour generation, these results are revealing about the potential impact of suburban development patterns on activities.

Trip chaining has generally been seen as something that increases the efficiency of engaging in a large variety of activities. On the other hand, as trips become more complex, households need to plan appropriately. No research to our knowledge has yet tried to ascertain the costs associated with planning more complex trips. All else equal, most individuals probably prefer to make uncomplicated trips to single destinations and would prefer to not engage in detailed planning of complex chains.

The implications that can be drawn from the study are somewhat limited by the dependent variable at the heart of the analysis. What they illustrate is that lower density environments, controlling for other key factors, seem to lead people to rely upon more complicated journeys to accomplish their travel goals. However, further analysis is needed to examine the relationship between more complex travel tours and total vehicle miles. While a cursory analysis suggests that more stops increases total vehicle mileage, this needs to be examined in terms of total activities for a household. The data cannot provide information on the mileage total from separate trips to the various linked locations. More efficient trips that are chained may result in lower mileage compared to the same trips being unlinked, given existing patterns of development, but from a planning perspective, clustering activities together can achieve the same effect, without the cost of adding to household planning burdens.

References

Adler, T and M Ben-Akiva (1979) A theoretical and empirical model of trip chaining behavior *Transportation Research B*. 13B. pp. 243-257.

Boarnet, M and R Crane (2001) *Travel by Design: The Influence of Urban Form on Travel*. Oxford Univ. Press. Pp. 240.

Bowman, J and M Ben-Akiva (2000) Activity-based disaggregate travel demand model system with activity schedules. *Transportation Research A*. 35 (1). Pp. 1-28.

Cervero, R. and K.M. Kockelman. (1997) Travel demand and the three Ds: Density, Diversity and Design. *Transportation Research Part D: Transport and Environment*, 2D. pp. 199-219.

Crane, R. (1996) On Form versus Function: Will the New Urbanism Reduce Traffic, or Increase it? *Journal of Planning Education and Research* 15 (2). pp. 117-126.

Davidson, D (1991) Impact of suburban employee trip chaining on transportation demand management. *Transportation Research Record*. No. 1321. pp. 82-89.

Ewing, R and R Cervero (2001) Travel and the Built Environment: A Synthesis. *Transportation Research Record*. No. 1780. pp. 87-114.

Gaerling, T, A Gaerling, A Johansson. (2000) Household choices of car-use reduction measures. *Transportation Research A*. 34. pp. 309-320.

Goulias, K, R Pendyala, R Kitamura. (1990) Practical method for the estimation of trip generation and trip chaining. *Transportation Research Record*. No. 1285. pp. 47-56

Kitamura, R. (1984) Incorporating trip chaining into analysis of destination choice. *Transportation Research B*, 1984. 18B (1). pp. 67-81.

Kitamura, R. (1985). Trip Chaining in a Linear City. *Transportation Research A*. 19A (2).

Krizek, K. (2000). Pretest-Posttest Strategy for Researching Neighborhood-Scale Urban Form and Travel Behavior. *Transportation Research Record*. No. 1722. pp. 48-55.

Krizek, K. (2003). Residential Relocation and Changes in Urban Travel: Does Neighborhood-Scale Urban Form Matter? *Journal of the American Planning Association*. 69 (3) pp.265-281.

Kuzmyak, J., G Douglas, F. Spielberg (2003) Land Use and Site Design. Ch. 15 in *Traveler Responses to Transportation System Changes* TCRP Report 95.

Lee, M, J Chung, M McNally. (2002). An Empirical Investigation of the Underlying Behavioral Process of Trip Chaining. *ITS Working Paper*. ITS-UCI-ASWP026.

Levinson, D and A Kumar (1995) Activity, Travel, and the Allocation of Time. *Journal of the American Planning Association*. pp. 458-470.

McGuckin, N and E Murakami (1999) Examining Trip-Chaining Behavior: A Comparison of Travel by Men and Women. *Transportation Research Record*. No. 1693. pp.79-85.

Mokhtarian, Patricia L. and Ilan Salomon, 2001, How derived is the demand for travel? Some conceptual and measurement considerations, *Transportation Research A*, 35(8): 695-719.

Nishii, K, K Kondo and R Kitamura. (1988) Empirical analysis of trip chaining behavior *Transportation Research Record.* No 1203. pp. 40-56.

Rosenbloom, S and E Burns. (1993). Gender Differences in Commuter Travel in Tucson: Implications for Travel Demand Management Programs. *Transportation Research Record* No. 1404 pp. 82-90.

Strathman, J and K Dueker. (1995). Understanding Trip Chaining in 1990 NPTS Special Reports on Trip and Vehicle Attributes Report FHWA-PL-95-033. FHWA, US Department of Transportation.

Thill, J and I Thomas. (1987) Toward conceptualizing trip-chaining behavior: a review Geographical Analysis, 19(1).

Wallace, B, J Barnes, and G Rutherford (2000) Evaluating the Effects of Traveler and Trip Characteristics on Trip Chaining, with Implications for Transportation Management Strategies. Transportation Research Record. No. 1718. pp. 97-106

Table 1
Distribution of number of stops in data

Number of stops	Total Cases	Share of Total
0	313,588	72.5
1	89,932	20.8
2	19,553	4.5
3	6,274	1.5
4	2,054	0.5
5	853	0.2
6	294	0.1
7	154	<0.1
8	48	<0.1
9	28	<0.1
10	15	<0.1
11	11	<0.1
12	5	<0.1
13	5	<0.1
14	1	<0.1
15	1	<0.1
17	1	<0.1
23	1	<0.1

Table 2

Trip characteristics for different residential population densities

Population Per Square Mile in the Traveler's Home Census Tract	Average Total Miles Per Tour	Average Distance per Tour Link	Average Trips Per Tour
Less than 100 per sq. mile (reference case)	30.0	12.3	2.60
100 – 500 per sq. mile	23.9	9.8	2.57
500 – 1000 per sq. mile	22.5	9.2	2.58
1000 – 2000 per sq. mile	21.5	8.8	2.55
2000 – 4000 per sq. mile	20.4	8.4	2.55
4000 – 10,000 per sq. mile	18.8	7.7	2.55
10,000 to 25,000 per sq. mile	17.9	7.2	2.52
25,000 or more per sq. mile	18.7	8.4	2.51

Population Per Square Mile	Average Tour Miles in Personal Vehicles	Average Tour Miles by Alternative Mode	Share of Tour Miles by Alternative Mode
Less than 100 per sq. mile (reference case)	27.5	2.4	8%
100 – 500 per sq. mile	21.9	2.0	8%
500 – 1000 per sq. mile	20.3	2.2	10%
1000 – 2000 per sq. mile	19.0	2.5	12%
2000 – 4000 per sq. mile	17.8	2.5	12%
4000 – 10,000 per sq. mile	16.3	2.5	13%
10,000 to 25,000 per sq. mile	13.6	4.3	24%
25,000 or more per sq. mile	10.2	8.5	45%

Table 3
Type of tour and numbers of stops

Trips Beginning at Home

	Trip Endpoint					
Number of Stops	Home		Other		Work	
0	673	1.42%	96622	83.39%	36129	85.12%
1	35662	75.03%	13971	12.06%	5191	12.23%
2	6931	14.58%	3572	3.08%	913	2.15%
3	2629	5.53%	1112	0.96%	155	0.37%
4	947	1.99%	340	0.29%	37	0.09%
5+	687	1.45%	255	0.22%	21	0.05%
Total	47529		115872		42446	

Trips Beginning at Work

	Trip Endpoint					
Number of Stops	Home		Other		Work	
0	31021	81.17%	8819	84.17%	870	16.18%
1	5430	14.21%	1238	11.82%	3657	68.02%
2	1292	3.38%	295	2.82%	625	11.63%
3	350	0.92%	77	0.73%	162	3.01%
4	71	0.19%	29	0.28%	41	0.76%
5+	51	0.13%	19	0.18%	21	0.39%
Total	38215		10477		5376	

Trips Beginning at Home

	Trip Endpoint					
Number of Stops	Home		Other		Work	
0	94650	80.26%	37990	80.44%	6814	87.93%
1	17197	14.58%	6864	14.53%	722	9.32%
2	4151	3.52%	1608	3.40%	166	2.14%
3	1260	1.07%	497	1.05%	32	0.41%
4	418	0.35%	162	0.34%	9	0.12%
5+	248	0.21%	109	0.23%	6	0.08%
Total	117924		47230		7749	

Table 4
Household structure and number of stops

	Number of Stops					
Household Structure	**0**	**1**	**2**	**3**	**4**	**5+**
One adult no children	69%	22%	6%	2%	1%	1%
Two or more adults no children	68%	23%	5%	2%	1%	0%
One adult, youngest child aged 0 to 5	75%	19%	4%	1%	0%	0%
Two or more adults, youngest child aged 0 to 5	75%	20%	4%	1%	0%	0%
One adult, youngest child aged 6-15	73%	20%	4%	1%	0%	0%
Two or more adults, youngest child aged 6-15	73%	21%	4%	1%	0%	0%
One adult, youngest child aged 16-21	71%	22%	5%	1%	0%	0%
Two or more adults, youngest child aged 16-21	71%	22%	5%	1%	0%	0%
One adult, retired, no children	74%	19%	4%	1%	0%	0%
Two or more adults, retired, no children	72%	21%	5%	2%	1%	0%

Table 5
Trip chain complexity: number of links in a tour

	Ordered probit		**Negative binomial**	
	Coeff.	z-stat	Coeff.	z-stat
Socioeconomic variables				
Age less than 16 (reference case)				
Age 16 to 18	0.068	4.89	0.074	3.88
Age 19 to 25	0.159	12.90	0.194	11.99
Age 26 to 45	0.274	29.99	0.338	28.89
Age 46 to 65	0.288	28.93	0.364	28.56
Age 66 to 75	0.261	20.13	0.333	20.48
Age 76 and over	0.217	14.19	0.286	15.06
HH members over 16 per vehicle	0.020	4.76	0.023	4.41
HH income	1.61E-07	2.27	1.960E-07	2.18
Gender: Male (Female is reference case)	-0.090	-20.60	-0.110	-19.72
Hispanic (non-hispanic is reference case)	-0.033	-3.11	-0.055	-4.06
Race: white (non-white is reference case)	0.009	1.31	0.003	0.39
Occupation: no job (reference case)				
Occupation: sales	-0.013	-1.63	-0.003	-0.28
Occupation: administrative	0.017	1.76	0.017	1.46
Occupation: manufacturing	-0.050	-5.46	-0.053	-4.61
Occupation: professional	-0.008	-1.08	-0.007	-0.77
Occupation: unknown	-0.014	-1.70	-0.003	-0.23
Household structure variables				
One adult no children (reference case)				
Two or more adults no children	-0.075	-7.54	-0.089	-7.07
One adult, youngest child aged 0 to 5	0.178	8.61	0.177	6.70
Two or more adults, youngest child aged 0 to 5	0.074	7.07	0.063	4.75
One adult, youngest child aged 6-15	0.041	2.65	0.033	1.66
Two or more adults, youngest child aged 6-15	-0.007	-0.71	-0.030	-2.35
One adult, youngest child aged 16-21	-0.049	-2.02	-0.079	-2.52
Two or more adults, youngest child aged 16-21	-0.094	-7.62	-0.118	-7.51
One adult, retired, no children	-0.010	-0.69	-0.018	-1.05
Two or more adults, retired, no children	-0.042	-3.59	-0.042	-2.88
Land use: residential population density variables				
Less than 100 per sq. mile (reference case)				
100 – 500 per sq. mile	-0.050	-7.31	-0.073	-8.38
500 – 1000 per sq. mile	-0.048	-5.70	-0.065	-6.12
1000 – 2000 per sq. mile	-0.071	-9.24	-0.103	-10.62
2000 – 4000 per sq. mile	-0.073	-10.40	-0.108	-12.20
4000 – 10,000 per sq. mile	-0.095	-13.12	-0.134	-14.75
10,000 to 25,000 per sq. mile	-0.179	-15.72	-0.234	-15.96
25,000 or more per sq. mile	-0.240	-16.00	-0.302	-15.62
Tour specific variables				
Modes used in tour (reference case: car only)				

Car and transit	-0.104	-0.73	-0.092	-0.63
Car and walk	-0.037	-0.95	-0.106	-3.26
Transit and walk	1.641	33.50	1.460	31.59
Car passenger and walk	1.751	56.91	1.563	58.82
Car passenger and transit	1.344	12.06	0.927	8.01
Type of tour (reference case: Work to Work tour)				
Home to Home tour	0.329	21.08	0.276	17.92
Home to Other tour	-1.389	-89.24	-1.424	-88.24
Home to Work tour	-1.571	-95.97	-1.754	-95.12
Other to Home tour	-1.270	-82.04	-1.270	-79.76
Other to Other tour	-1.303	-80.17	-1.313	-75.46
Other to Work tour	-1.668	-71.92	-1.889	-58.35
Work to Home tour	-1.374	-84.35	-1.422	-80.15
Work to Other tour	-1.503	-73.40	-1.591	-61.89
Day of week of tour (reference case: Monday)				
Tuesday	-0.025	-3.29	-0.035	-3.63
Wednesday	-0.015	-1.99	-0.030	-3.20
Thursday	-0.021	-2.75	-0.032	-3.23
Friday	0.013	1.68	0.015	1.55
Saturday	0.023	2.90	0.026	2.66
Sunday	-0.141	-17.26	-0.197	-18.71
Tour before Sept 11, 2001	0.014	3.14	0.017	2.99
Aveage link speed	0.000183	5.16	0.000171	5.27
Constant			-0.130	-5.18
Cut point 1	-0.38551			
Cut point 2	0.784014			
Cut point 3	1.372879			
Cut point 4	1.837164			
Cut point 5	2.191541			
Alpha			0.152	
N	432,719		432,719	
L(0)	-348535.3		-318229.73	
L(β)	-290351.61		-306361.15	
Pseudo R^2	0.1669		0.1277	

Table 6
Predicted changes compared to reference case (ordered probit model)

	0 stops	1 stop	2 stops	3 stops	4 stops	5 or more stops
Reference case	33.70%	43.60%	13.65%	5.47%	2.02%	1.55%
Socioeconomic variables						
Age less than 16 (reference case)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Age 16 to 18	-7.31%	0.80%	6.94%	10.88%	14.09%	18.53%
Age 19 to 25	-16.61%	1.21%	16.07%	26.24%	34.88%	47.49%
Age 26 to 45	-27.71%	0.66%	27.28%	47.06%	64.79%	92.51%
Age 46 to 65	-28.99%	0.52%	28.60%	49.67%	68.69%	98.67%
Age 66 to 75	-26.50%	0.78%	26.05%	44.64%	61.22%	86.93%
Age 76 and over	-22.25%	1.08%	21.74%	36.46%	49.32%	68.73%
HH members over 16 per vehicle	-0.23%	0.03%	0.21%	0.33%	0.41%	0.53%
HH income	-0.10%	0.01%	0.10%	0.15%	0.19%	0.24%
Gender: Male (Female is reference case)	9.98%	-1.67%	-9.12%	-13.37%	-16.57%	-20.62%
Hispanic (non-hispanic is reference case)	3.57%	-0.52%	-3.31%	-4.97%	-6.26%	-7.93%
Race: white (non-white is reference case)	-0.99%	0.13%	0.92%	1.41%	1.80%	2.31%
Occupation: no job (reference case)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Occupation: sales	1.39%	-0.19%	-1.30%	-1.97%	-2.49%	-3.18%
Occupation: administrative	-1.84%	0.24%	1.73%	2.65%	3.38%	4.36%
Occupation: manufacturing	5.48%	-0.84%	-5.06%	-7.54%	-9.45%	-11.91%
Occupation: professional	0.88%	-0.12%	-0.82%	-1.25%	-1.58%	-2.02%
Occupation: unknown	1.54%	-0.22%	-1.44%	-2.18%	-2.75%	-3.52%
Household structure variables						
One adult no children (reference case)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Two or more adults no children	8.21%	-1.33%	-7.54%	-11.11%	-13.84%	-17.30%
One adult, youngest child aged 0 to 5	-18.47%	1.20%	17.92%	29.52%	39.46%	54.12%
Two or more adults, youngest child aged 0 to 5	-7.90%	0.84%	7.51%	11.80%	15.30%	20.16%
One adult, youngest child aged 6-15	-4.43%	0.53%	4.18%	6.47%	8.31%	10.82%
Two or more adults, youngest child aged 6-15	0.78%	-0.11%	-0.73%	-1.11%	-1.40%	-1.79%
One adult, youngest child aged 16-21	5.33%	-0.82%	-4.93%	-7.35%	-9.21%	-11.62%
Two or more adults, youngest child aged 16-21	10.40%	-1.76%	-9.50%	-13.90%	-17.22%	-21.40%
One adult, retired, no children	1.04%	-0.14%	-0.97%	-1.47%	-1.86%	-2.38%
Two or more adults, retired, no children	4.56%	-0.69%	-4.22%	-6.31%	-7.93%	-10.02%
Land use: residential population density variables						
Less than 100 per sq. mile (reference case)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
100 – 500 per sq. mile	5.53%	-0.85%	-5.11%	-7.60%	-9.53%	-12.01%
500 – 1000 per sq. mile	5.24%	-0.80%	-4.84%	-7.22%	-9.05%	-11.42%
1000 – 2000 per sq. mile	7.85%	-1.26%	-7.22%	-10.66%	-13.28%	-16.62%
2000 – 4000 per sq. mile	8.06%	-1.30%	-7.40%	-10.92%	-13.60%	-17.01%
4000 – 10,000 per sq. mile	10.45%	-1.77%	-9.54%	-13.96%	-17.29%	-21.48%
10,000 to 25,000 per sq. mile	20.06%	-3.97%	-17.90%	-25.34%	-30.72%	-37.17%

25,000 or more per sq. mile	27.07%	-5.89%	-23.74%	-32.83%	-39.23%	-46.64%
Tour specific variables						
Modes used in tour (reference case: car only)						
Car and transit	4.00%	-0.59%	-3.71%	-5.55%	-6.98%	-8.84%
Car and walk	11.51%	-1.98%	-10.49%	-15.28%	-18.88%	-23.38%
Transit and walk	-94.18%	-61.82%	42.62%	234.62%	556.48%	1852.80%
Car passenger and walk	-95.57%	-67.15%	33.04%	230.10%	576.97%	2106.15%
Car passenger and transit	-88.48%	-45.63%	62.38%	227.16%	468.93%	1241.36%
Type of tour (reference case: Work to Work tour)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Home to Home tour	-32.70%	-0.01%	32.41%	57.45%	80.50%	117.73%
Home to Other tour	147.33%	-65.54%	-90.42%	-95.45%	-97.46%	-98.74%
Home to Work tour	159.66%	-73.67%	-93.88%	-97.37%	-98.64%	-99.38%
Other to Home tour	138.01%	-59.60%	-87.39%	-93.61%	-96.26%	-98.03%
Other to Other tour	140.73%	-61.32%	-88.31%	-94.18%	-96.64%	-98.26%
Other to Work tour	165.22%	-77.44%	-95.23%	-98.05%	-99.04%	-99.58%
Work to Home tour	146.25%	-64.85%	-90.09%	-95.25%	-97.34%	-98.66%
Work to Other tour	155.31%	-70.77%	-92.73%	-96.75%	-98.28%	-99.18%
Day of week of tour (reference case: Monday)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Tuesday	2.75%	-0.40%	-2.56%	-3.85%	-4.86%	-6.18%
Wednesday	1.60%	-0.23%	-1.50%	-2.26%	-2.86%	-3.65%
Thursday	2.34%	-0.33%	-2.18%	-3.28%	-4.14%	-5.27%
Friday	-1.38%	0.18%	1.29%	1.98%	2.52%	3.25%
Saturday	-2.46%	0.31%	2.31%	3.55%	4.54%	5.87%
Sunday	15.72%	-2.91%	-14.18%	-20.36%	-24.92%	-30.51%
Tour before Sept 11, 2001	-1.50%	0.19%	1.41%	2.16%	2.75%	3.54%
Aveage link speed	-0.05%	0.01%	0.05%	0.07%	0.09%	0.12%

Table 7
Household tour model: number of tours per household

	Ordered probit		**Negative binomial**	
	Coeff.	z-stat	Coeff.	z-stat
HH members over 16 per vehicle	0.047	4.52	0.035	7.70
HH income	5.360E-06	30.57	2.440E-06	32.82
Household structure variables				
One adult no children (reference case)				
Two or more adults no children	0.747	44.99	0.506	54.38
One adult, youngest child aged 0 to 5	1.233	23.37	0.896	40.31
Two or more adults, youngest child aged 0 to 5	1.342	64.83	1.076	110.84
One adult, youngest child aged 6-15	1.224	34.06	0.815	51.86
Two or more adults, youngest child aged 6-15	1.519	71.01	1.140	118.23
One adult, youngest child aged 16-21	0.932	18.22	0.599	25.01
Two or more adults, youngest child aged 16-21	1.521	47.39	0.969	78.19
One adult, retired, no children	0.038	1.99	0.079	6.71
Two or more adults, retired, no children	0.700	38.50	0.505	50.38
Land use: residential population density variables				
Less than 100 per sq. mile (reference case)				
100 – 500 per sq. mile	0.045	2.65	0.013	1.73
500 – 1000 per sq. mile	0.074	3.49	0.034	3.63
1000 – 2000 per sq. mile	0.123	6.38	0.050	5.87
2000 – 4000 per sq. mile	0.123	7.07	0.050	6.48
4000 – 10,000 per sq. mile	0.095	5.45	0.042	5.39
10,000 to 25,000 per sq. mile	0.017	0.70	-0.002	-0.15
25,000 or more per sq. mile	-0.059	-1.98	-0.090	-6.16
Average HH link speed	-9.850E-05	-0.73	-1.871E-04	-2.31
Constant			1.096	103.94
Cut point 1	-0.877			
Cut point 2	0.043			
Cut point 3	0.394			
Cut point 4	0.847			
Alpha			0.152	
N	59,351		59,351	
L(0)	-67663.204		-160002.7	
L(β)	-60588.268		-156806.94	
Pseudo R2	0.1046		0.0820	